**Space Technology Research Grants**

# Computationally Tractable Reachability Subspace Surfaces Applied to Space Operations

Completed Technology Project (2016 - 2020)

## Project Introduction

The overall objective of the proposed work is to tractably compute reachability subspace surfaces through distributed control of point solutions to ensure uniform reachability set surface coverage found using optimal control and continuation methods. A Python or C software library containing reachability subspace surface computation methods applied to autonomous space operations scenarios will be developed. The following secondary objectives will support the development of the central objective of this research. The first research objective is to formulate a reachability subspace surface point solution optimal control problem statement using continuation methods. Continuation methods take the conditions of optimality and explore point solutions on the manifold enforcing dynamics, initial conditions, and first order conditions of optimality. The second research objective is to investigate novel methods to frame the reachability subspace computation problem as a distributed control problem with independent point solution agents. The proposed approach uses distributed control methods by treating each point solution as a distributed agent and solving the surface coverage problem. The final research objective is to extend existing distributed uniform coverage control policies to compute reachability subspaces in a computationally tractable manner. As manned exploration missions take humans deeper into space, there is an increased reliance on autonomous systems to assist in the operation of spacecraft and deep space operations as a whole. Consequently, the 2015 NASA Technology Roadmap emphasizes that the success of complex missions to scientifically valuable targets such as Near-Earth Asteroids and Mars depend on the improved decision-making performance by on-board autonomous systems. The concept of reachability directly addresses these issues regarding system level autonomy. Unfortunately, reachability computation suffers from the curse of dimensionality, and for large state spaces is computationally intractable. However, in many cases the end user is only interested in a subset of states in a reachability analysis calculation. In this way, it is hoped that only the computational cost of the subspace of interest is incurred as opposed to the computational costs due to the full description of the reachability set. The computation of reachability subspace surfaces can greatly improve multiple aspects of overall system level autonomy (NASA Technology Roadmap TA 4.5) for space operations. These computations allow the prediction of future states which assists in the autonomous planning of system activities and detection of potential system faults. Furthermore, the computation of reachability subspace surfaces has many additional applications in other NASA Technology Roadmap Technology Areas (TA) such as Orbital Debris Tracking and Characterization, Autonomous Rendezvous and Docking, Proximity Operations, Spacecraft Formation Flight, and On-board Auto Navigation and Maneuvering (TA 5.7, 4.6, 5.4).

## Anticipated Benefits

The computation of reachability subspace surfaces can greatly improve


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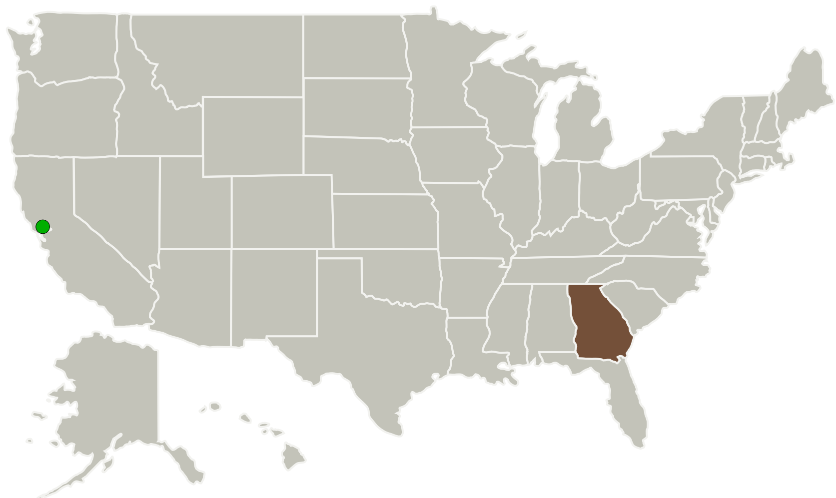
## Table of Contents

multiple aspects of overall system level autonomy (NASA Technology Roadmap TA 4.5) for space operations. These computations allow the prediction of future states which assists in the autonomous planning of system activities and detection of potential system faults. Furthermore, the computation of reachability subspace surfaces has many additional applications in other NASA Technology Roadmap Technology Areas (TA) such as Orbital Debris Tracking and Characterization, Autonomous Rendezvous and Docking, Proximity Operations, Spacecraft Formation Flight, and On-board Auto Navigation and Maneuvering (TA 5.7, 4.6, 5.4).

### Primary U.S. Work Locations and Key Partners



| Organizations Performing Work | Role | Type | Location |
| --- | --- | --- | --- |
| Georgia Institute of Technology-Main Campus(GA Tech) | Lead Organization | Academia | Atlanta, Georgia |
| Ames Research Center(ARC) | Supporting Organization | NASA Center | Moffett Field, California |

| Primary U.S. Work Locations |
| --- |
| Georgia |

## Organizational Responsibility

**Responsible Mission Directorate:**

Space Technology Mission Directorate (STMD)

**Lead Organization:**

Georgia Institute of Technology-Main Campus (GA Tech)

**Responsible Program:**

Space Technology Research Grants

## Project Management

**Program Director:**

Claudia M Meyer

**Program Manager:**

Hung D Nguyen

**Principal Investigator:**

Glenn Lightsey

**Co-Investigator:**

Julian D Brew

**Project Website:**

https://www.nasa.gov/strg#.VQb6T0jJzyE

## Technology Maturity (TRL)

Start: **2**
Current: **2**
Estimated End: **3**

1 2 3 4 5 6 7 8 9

Applied Research | Development | Demo & Test

## Technology Areas

**Primary:**

- TX04 Robotic Systems
  - └ TX04.3 Manipulation
    - └ TX04.3.2 Grappling Technologies

## Target Destinations

Earth, The Moon, Mars